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US ARMY RESEARCH INSTITUTE  
OF  
ENVIRONMENTAL MEDICINE  
Natick, Massachusetts

MARCH 1982



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EFFECTIVENESS OF ICE (WATER) PACKETS VESTS IN  
REDUCING HEAT STRESS

by  
GEORGE F. FONSECA

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during heat exposure to three hot environments. The number of ice packets attached to a vest varied from 43 to 91 ice packets. When approximately 50% of the torso surface area is covered by ice packets, each additional ice packet added to the vest increases the torso cooling to a greater degree than an ice packet added to a vest with less than 50% torso surface area coverage. Interface temperature between two ice packets and the torso surface and the temperature changes inside one ice packet during and experiment, were also measured.

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## FOREWORD

Biophysical studies investigating the merits of various auxiliary cooling systems are in progress to provide a technical basis for selecting an auxiliary cooling system for combat vehicle crewmen. One method of providing temperature controlled cooling to these combat vehicle crewmen is to use water-cooled undergarments having a continuous flow of cold water through their tubing. Another possible method is to use an air-cooling system that will circulate either 1) just ambient air within the clothing of these crewmen or 2) air that is temperature and relative humidity regulated. All of these auxiliary cooling systems require a continuous source of energy and some form of connecting hoses or lines. The ice (water) packets vest is an alternative auxiliary cooling system. This auxiliary cooling system does not require a continuous source of energy or any umbilical connections but has the disadvantage that it does not provide continuous, controlled cooling to the wearer; it provides an initial high rate of cooling which tapers off to zero cooling with continuous use. During its operating lifetime, however, it can provide cooling to an air or combat vehicle crewman independently of any vehicle energy. It thus has specific application for short sorties from fixed bases. This approach also could permit some of a fighting vehicle's energy to be utilized when its engine is running to provide the required refrigeration to freeze the ice packets in the vest; an ice packets vest then could be worn when the vehicle is stopped or the crew are working outside and vehicle energy is not available. The subject of this technical report is the cooling provided over the torso area by an ice packets vest<sup>1</sup>.

<sup>1</sup> The ice packets vests were furnished by Ms. Shelly Harrity of Gentex Corporation, (717-282-3550).

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### ABSTRACT

The auxiliary cooling provided over the torso area by each of two similar ice (water) packets vests was directly measured on a life-sized sectional manikin. These vests were worn with a combat vehicle crewman (CVC) ensemble plus a complete chemical protective (CW) suit. Cooling rates provided (watts) versus time were determined for a completely wet (maximal sweating) skin condition during heat exposure to three hot environments. The number of ice packets attached to a vest varied from 43 to 91 ice packets. When approximately 50% of the torso surface area is covered by ice packets, each additional ice packet added to the vest increases the torso cooling to a greater degree than an ice packet added to a vest with less than 50% torso surface area coverage. Interface temperature between two ice packets and the torso surface and the temperature changes inside one ice packet during an experiment, were also measured.

## 1. INTRODUCTION

The armored fighting vehicle crewmen of the 1940's era, shown with their vehicle in Figure 1, were primarily concerned with the ballistic protection (armor), the firepower and speed provided by their vehicle. Fortunately for these crewmen, the probability of their being exposed to hazardous chemical and/or biological environments was very low and they could be outfitted with "comfortable" clothing components which could be added, or removed, depending on the environmental conditions. Modern armored-fighting-vehicle crewmen, however, have inherited not only this potential problem of exposure to hazardous chemical and/or biological environments but also its present solution, complete encapsulation within a chemical protective (CW) suit; this solution results in a high probability for a crewman to have a serious heat stress problem when exposure to this man-made hazardous environment is combined with a hot environment. Some type of auxiliary cooling is required for these modern armored-fighting vehicle crewmen operating in unventilated, closed vehicles in hot environments, particularly when additional protective clothing (CW, armor, etc.) is worn. These auxiliary cooling systems must not only be feasible, but practical. Auxiliary cooling systems which require continuous use of vehicle energy have the potential to provide continuous, regulated cooling to a combat vehicle crewman for an unlimited time. These auxiliary cooling systems can also adjust to the increased or decreased cooling demand required by changes in the crewman's metabolic rate as his tasks vary. However, sufficient vehicle energy has to be readily available should an armored fighting vehicle suddenly be engaged with an enemy. Therefore, once the vehicle stops, the energy demand on the vehicle has to be minimized to conserve vehicle energy and, if vehicle equipment noise has to be kept to a minimum, operating a refrigeration unit to supply cooling fluid (water or air) to these cooling undergarments will have to be curtailed. (6)

A recently completed study determined the cooling provided by five different water-cooled undergarments (3). These water-cooled undergarments are capable, either separately or in combination, of providing continuous cooling over the 80 to 400 watt range required for ground vehicle crewmen. When operating under severe heat stress conditions, these water-cooled undergarments are a welcome addition to the clothing worn by these crewmen. However, continuous vehicle energy expenditures are required to supply these water-cooled undergarments with cooling water, and there are difficulties of umbilical connections if work has to be performed outside the vehicle (e.g. repair track, resupply ammunition). It appeared reasonable to investigate other auxiliary cooling systems which have the capability of providing cooling to these crewmen, even when the vehicle is stopped and vehicle energy cannot be used; thus, a solid technical basis would be available to ensure the best possible choice of an auxiliary cooling system for these crewmen. Portable personal cooling systems have used both dry ice cooling (1,5) and ice (water) cooling (7); these cooling systems do not require any vehicle energy expenditure once the frozen ice (dry or water) is attached to the supporting undergarment (e.g. vest). This study considers an ice (water) packets vest which has the potential of providing auxiliary cooling to these crewmen over short periods of time (2-4 hours) when energy is not available to operate more sophisticated auxiliary cooling systems.

## 2. EXPERIMENTAL METHOD

The electrically heated sectional manikin used consists of six sections: head, torso, arms, hands, legs and feet. The manikin was placed in a standing position in a large temperature and humidity controlled chamber (chamber dimensions: length 5.8 m, width 3.9 m and height 2.7 m); chamber environmental conditions were either 29°C (85°F), at 85% relative humidity, 35°C (95°F), at

62% relative humidity or 52°C (125°F), at 25% relative humidity. The heat loss from the manikin surface is determined from the electrical watts required to maintain the manikin surface temperature constant. Electrical watts supplied to the torso area maintain this area at an average temperature of 35°C (95°F). Since the cooling provided by the ice packets vest is time dependent, cooling rates are plotted against the torso cooling time period when the ice packets vest is providing cooling over the torso. This torso cooling time period starts at time zero when the ice packets vest is zippered up on the manikin. The cooling rate provided over the torso by the ice packets vest is expressed in terms of cooling watts. Experimentally, these cooling rates are equal to the difference in electrical watts supplied to the torso when the ice packets vest is providing cooling to the torso and when the unfrozen ice packets vest is dressed on the manikin. These results are also expressed in terms of the heat exchanges between the torso and both the ice packets vest and the hot environment, (designated "torso heat exchange") and the heat exchanges over all the manikin surface (head, torso, arms, hands, legs and feet), (designated "total heat exchange"). The total cooling provided by an ice-packets vest over a torso cooling period is given in the energy unit of watt-hours (1 watt-hour = 0.86 kcal). This energy unit is also used to express the cooling potential of an ice-packets vest based on the weight of ice in the packets attached to a vest.

Ice packets were attached by velcro tapes to each of two similar vests; vest #1 with a maximum of 72 ice packets attached and vest #2 with a maximum of 91 ice packets. The 91 packets vest presented a continuous surface of ice facing the torso surface and, practically, is the largest number of ice packets that the velcro strips on the vest could hold without an ice packet falling off. Figure 2 shows both vests, #1 opened up to show the ice packets attached to the

velcro strips on the inner surface of the vest and vest #2 in the zippered up position. One experiment with vest #1 was conducted with 40% of the ice packets removed; packets in every other vertical strip were removed except that both vertical strips along the front zipper were left intact. Similarly, vest #2 was redressed with the ice packets slightly less crowded together (85 ice packets attached to the vest) to investigate the effect on the torso cooling with slightly fewer ice packets than the vest could hold. These ice packets vary somewhat in size and water content. Each packet has a contact surface area of approximately  $64 \text{ cm}^2$  and contains about 47 grams of water. A vest with these ice packets attached was frozen overnight in a walk-in freezer (air temperature about  $-20^{\circ}\text{C}$  ( $-4^{\circ}\text{F}$ )) and removed from the freezer about two minutes prior to dressing on the manikin.

The components of the combat vehicle crewman (CVC) ensemble and the complete chemical protective (CW) suit worn with an ice packets vest are given in Table I. A photograph of this clothing dressed on the manikin is shown in Figure 3. All clothing components dressed on the manikin were originally at the temperature of the chamber air, except for the ice packets vest.

### 3. RESULTS

#### A. HEAT TRANSFER PROPERTIES OF THE COMBAT VEHICLE CREWMAN (CVC) ENSEMBLE WORN WITH THE COMPLETE CHEMICAL PROTECTIVE (CW) SUIT

Table II gives the heat transfer properties of the combat vehicle crewman (CVC) ensemble worn with a complete chemical protective (CW) suit. These values of insulation (clo) and evaporative heat transfer ( $i_m/\text{clo}$ ) are used to calculate the conduction/convection heat exchanges and the maximum

evaporative heat transfer from the manikin. Figure 4 illustrates the distribution of the heat transfer to or from the manikin surfaces for this ensemble during exposure to a hot environment of 52°C (125°F), 25% relative humidity. This bar graph dramatically illustrates the problem with heat stress that a combat vehicle crewman would experience wearing this clothing while exposed to this hot environment; the clothing restricts evaporative heat loss to a greater extent than it restricts conductive/convective heat gain. All metabolic heat input to the body would go into heat storage, continually increasing body temperature as long as the body is exposed to this hot environment. Goldman (4) has estimated the tolerance time for continuous, moderately-heavy work in environments above 24°C (75°F) when completely encapsulated in a chemical protective (CW) suit to be only about 30 minutes. This figure presents a simple illustration of the need to provide some form of auxiliary cooling to a combat vehicle crewman dressed in a complete chemical protective suit for an indefinite period of time in a severely hot environment.

#### B. HEAT EXCHANGES (WATTS) OVER THE COMPLETELY WET (MAXIMAL SWEATING) TORSO WHEN AN ICE PACKETS VEST IS WORN IN THREE HOT CHAMBER ENVIRONMENTS

##### 1. Ice Packets Vest #1

The heat losses from the torso are the actual watts supplied to the torso during an experiment. The decrease in torso watts with torso cooling time is shown in Figure 5 for an exposure to each of three hot chamber environments. These curves all have maximum values at time 0 minutes, which decrease with time as the ice in the ice packets melts. At least 160 watts is lost from the torso during the first hour of cooling for exposure to all three chamber



environments (Table III), except for the condition when 40% of the ice packets are removed from the ice packets vest; for this condition, about 150 watts are removed from the torso during the first hour. The total heat losses from the torso during each cooling period were: 381 watt-hours for a chamber environment of 29°C (85°F), 85% relative humidity; 362 watt-hours for a chamber environment of 35°C (95°F), 62% relative humidity; 278 watt-hours for a chamber environment of 52°C (125°F), 25% relative humidity; and 187 watt-hours for the latter chamber environment when 40% of the ice packets were removed from the vest. When the ice in the vest is all melted, no cooling would be provided and the torso would receive a net heat gain from a hot environment of 52°C (125°F), 25% relative humidity. Practically, this heat gain would result in the skin temperature of the torso rising above 35°C (95°F).

## 2. Ice Packets Vest #2

Figure 6 gives the decrease in torso watts with cooling time for ice packets vest #2 during exposures to each of the three hot environments. The relationships among these three curves are similar to those for the three curves shown in Figure 5; the effect of increasing the temperature of the environment is to decrease the torso heat loss over the torso cooling period. The total heat loss (watt-hours removed from the torso during each four hour torso cooling period) were: 522 watt-hours for a chamber environment of 29°C (85°F), 85% relative humidity; 491 watt-hours for a chamber environment of 35°C (95°F), 62% relative humidity; and 444 watt-hours for a chamber environment of 52°C (125°F), 25% relative humidity. The hourly rates of heat loss from the torso for exposure to each of the three hot environments are given in Table IV. The effect of increasing the number of ice packets dressed on the vest by 26%, (i.e., from 71 to 91 ice packets), is to increase both the heat removed from the torso during

the cooling period, and the length of time during which some benefit would be obtained from the ice packets vest.

### C. COOLING BENEFITS OF AN ICE PACKETS VEST WORN IN THREE HOT CHAMBER ENVIRONMENTS

#### 1. Ice Packets Vest #1

The cooling benefit of an ice packets vest is equal to the net heat removed from the torso by the melting ice. It is the difference between the watts supplied to the torso when the ice packets vest is providing cooling to the torso and the watts supplied after the ice packets have thawed. Figure 7 shows the decrease in cooling beginning at time 0 minutes, when ice packets vest #1 was dressed on the manikin, in each of three hot chamber environments. These decreases in cooling with time are based on an average torso temperature of  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ). The cooling provided by each individual ice packet will vary with the time and with its contact pressure with the torso surface, and with any heating effect of the clothing and hot environment. It is evident from this figure that the environmental conditions have an effect on both the cooling provided by this vest and the time this cooling is being provided. In environments of  $29^{\circ}\text{C}$  ( $85^{\circ}\text{F}$ ), 85% relative humidity, and also of  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ), 62% relative humidity, this ice packets vest is still providing some cooling for up to four hours of operation. However, in an environment of  $52^{\circ}\text{C}$  ( $125^{\circ}\text{F}$ ), 25% relative humidity, any benefit from wearing this ice packets vest is negligible after about three hours of operation. When 40% of the ice packets are removed from the vest, the cooling provided over the torso is negligible after about two hours of operation. Once the ice is completely melted, the water temperature continually increases and approaches the temperature of the torso surface. There is no condensation

of moisture onto these ice packets from the surrounding air trapped within the clothing layers once the temperature of the plastic ice packets exceeds the dew point of this surrounding air. This is a different experimental condition than when a water-cooled undergarment is worn. The surface of the tubing of a water-cooled undergarment can constantly be maintained at or below the dew point temperature of the surrounding air. Condensation of moisture from the air trapped within the clothing augments the heat loss from the skin surface by continually wicking and blotting this moisture onto the larger surface areas of the clothing. This evaporation/condensation cycle, which provides some additional increased heat loss from the man, apparently occurs within the clothing in a way similar to the evaporation/condensation within a double-walled vapor barrier-type boot worn in arctic environments, which has been reported by Breckenridge (2).

Table V presents the average rates of cooling provided over the torso in hourly increments. These results show that at least 145 watts of cooling are provided over the torso during the first hour of cooling in all three hot chamber environments even when 40% of the ice packets are removed from the vest. During this initial transient period, greater cooling is provided over the torso by this ice packets vest (# 1) when exposure is in the most severe hot chamber environment ( $52^{\circ}\text{C}$  ( $125^{\circ}\text{F}$ ), 25% relative humidity). This dependence of torso cooling on the hot chamber environment during the first hour of the cooling period apparently results from replacing the existing temperature gradient outward from the manikin surface to the environment, which is dependent on the hot environment, by a cold surface which is at a constant temperature (i.e. of the ice in the packets of the vest), independent of the chamber environment; the steeper the initial temperature gradient from the torso surface outward to the environment, the more effective will be this initial cooling provided by an ice

packets vest. Although the cooling rate over the first hour of torso cooling is greater for exposure to the most severe hot chamber environment, the ice in the packets is melting at a greater rate because of the increased heat gain from the hot environment. This is evident from the average cooling watts given in Table V for the second hour cooling period; the cooling rate drops dramatically during this second hour of cooling for exposure to the most severe hot chamber environment and is considerably less than the cooling rates obtained for exposure to the other two hot chamber environments.

In all three hot chamber environments, an average cooling rate of more than 130 watts can be provided over a two hour period and 150 watts can be provided over the first hour even when there is a 40% reduction in the number of ice packets attached to this vest. This ice packets vest is capable of removing about 315 watt-hours from a body exposed to either a 29°C (85°F), 85% relative humidity environment or a 35°C (95°F) 62% relative humidity environment, and about 290 watt-hours at 52°C (125°F), 25% relative humidity environment. Torso cooling extends for up to four hours when exposure takes place in a 29°C (85°F) or 35°C (95°F) temperature environment. However, at a chamber air temperature of 52°C (125°F), cooling time is limited to two and a half hours.

## 2. Ice Packets Vest #2

The torso cooling watts versus cooling time for ice packets vest #2 are given in Figure 8. The closeness of the three curves indicates that the environmental conditions have little effect on the torso cooling watts for up to four hours of cooling time. This result differs from that obtained in Figure 7 for ice packets vest #1; the torso cooling curve in Figure 7 for the hot environment of 52°C (125°F) definitely indicates a shorter effective cooling time than the

curves for the other two hot environments. Apparently, the magnitude of this difference is dependent upon the proportion of the surface area of an ice packet that exchanges heat with the torso surface or another ice packet compared with the surface area that is surrounded by air and exchanging heat with a hot environment; this latter heat exchange would increase with increasing temperature of the hot environment. Full coverage of the torso area by ice packets, as with ice packets vest #2, would provide the minimum heat exchange between an ice packet and a hot environment and thereby minimize the effect of different hot environments on the torso cooling watts during a cooling period.

Table VI presents the average rates of cooling provided over the torso in hourly increments. Like the cooling obtained from vest #1, the greatest cooling during the first hour is provided when exposure is in the most severe hot environment ( $52^{\circ}\text{C}$  ( $125^{\circ}\text{F}$ ), 25% relative humidity). In all three hot chamber environments, the average cooling provided over the torso for the first two hours of cooling is about 165 watts. One of these ice packets vest when dressed with 91 ice packets is capable of removing about 455 watt-hours of heat from the torso over a four-hour cooling period.

#### D. COMPARISON BETWEEN THE AMOUNT OF TORSO COOLING AND THE NUMBER OF ICE PACKETS ATTACHED TO A VEST

Figure 9 shows the torso cooling in watt-hours for various cooling periods plotted against the number of ice packets attached to a vest. The duration of cooling varies from a minimum of two hours for the experiment when 40% of the ice packets were removed from vest #1, to a maximum of four hours for the results obtained with vest #2. Although these curves are only eye-fitted, their shape does appear to change from part A for the initial one-hour cooling period

to part D for a four-hour cooling period. A power curve fit for the data plotted in part D for a four-hour cooling period suggests that each additional ice packet added to a vest over and above a basic number of about 46 ice packets provides more efficient cooling over the torso than each additional ice packet added to less than 46 ice packets attached to a vest; 5.4 watt-hours of cooling per ice packet to 4.2 watt-hours of cooling per ice packet, respectively.

Expressed another way, each kilogram of ice which is initially at a temperature of  $-20^{\circ}\text{C}$  ( $-4^{\circ}\text{F}$ ) has the potential of providing about 145 watt-hours ( $12 + 93 + 40 = 145$  watt-hrs per kg) of cooling to the torso surface and/or a hot environment before the melted ice temperature reaches the average torso skin temperature of  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ). Calculating the efficiency of cooling provided over a four-hour torso cooling period by an ice packets vest based on the potential cooling provided by a kilogram of ice, gives 73% when 91 ice packets are attached to a vest; 69% when 72 ice packets are attached to a vest; a further reduction to 44 ice packets attached to a vest reduces the torso cooling efficiency to 63%. These rough calculations indicate that the cooling efficiency of an ice packets vest should increase with the number of ice packets attached to the vest up to the limit of total torso surface area coverage.

#### E. TOTAL RATES OF HEAT EXCHANGE (WATTS) OVER THE COMPLETELY WET (MAXIMAL SWEATING) MANIKIN SKIN SURFACE AREA ( $1.79\text{ m}^2$ ) WHEN AN ICE PACKETS VEST IS WORN IN THREE HOT CHAMBER ENVIRONMENTS

The total rates of heat exchange are equal to the manikin watts measured over the completely wet (maximal sweating) surface area of the head, torso, arms, hands, legs and feet. These total heat exchanges are dependent upon the hot chamber environment in which exposure takes place. The total heat

exchange over a four-hour cooling period when 91 ice packets are attached to a vest are: 760 watt-hours when exposure is in an  $29^{\circ}\text{C}$  ( $85^{\circ}\text{F}$ ), 85% relative humidity environment; 690 watt-hours when exposure is in an  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ), 62% relative humidity environment; and 370 watt-hours when exposure is in an  $52^{\circ}\text{C}$  ( $125^{\circ}\text{F}$ ), 25% relative humidity environment. Similar to the condition for the heat exchanges over the torso when the ice packets vest provides no cooling, the total manikin heat exchange in a chamber environment of  $52^{\circ}\text{C}$  ( $125^{\circ}\text{F}$ ), 25% relative humidity would be negative indicating that there is a net heat gain from this hot environment rather than a net heat loss. Practically, this heat gain would result in the skin temperatures over the total manikin surface area increasing above  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ). Increasing the hot chamber air temperature from  $29^{\circ}\text{C}$  ( $85^{\circ}\text{F}$ ) to  $52^{\circ}\text{C}$  ( $125^{\circ}\text{F}$ ) decreases the total heat exchange over the completely wet (maximal sweating) manikin surface area by about 50%.

#### 4. DISCUSSION

The experimental results of this study are presented in terms of three heat transfer expressions: 1) heat exchanges over the torso, 2) torso cooling watts, and 3) total rates of heat exchange over the surface of the manikin. The heat exchanges over the torso are the actual electrical watts supplied to the torso during an experiment. The torso cooling watts are equal to the net heat removed from the torso by the ice packets vest; this is the difference between the electrical watts supplied to the torso when the ice packets vest is worn with frozen ice, and the watts supplied when the unfrozen ice packets vest is dressed on the manikin. The total rates of heat exchange over the manikin surface are equal to the total electrical watts supplied to the manikin; i.e., the sum of the electrical watts supplied to the head, torso, arms, hands, legs and feet.

Since the ice packets vest does not provide continuous and regulated cooling over an indefinite time period, exposure to a hot environment would either be time limited, or involve backup ice packets vests which would require redressing every 2 to 4 hours when the ice in the packets was completely melted and water temperature approached skin temperature. Replacing an ice packets vest would obviously have to be accomplished when a crewman was in a standby position. However, this cooling is supplied noise free and independent of any vehicle energy source or umbilical cord that would limit a crewman's mobility.

The durability of the seals on these particular ice packets will have to be improved if this ice packets vest is to be used in large-scale field operations. During the experiments a total of twenty ice packets leaked at an end seam. Also, the Velcro seals came off of several packets when the packets were frozen; these were easily replaced once the packet warmed up. Finally, several packets fell off the vest while dressing the manikin. Possibly using wider velcro strips and/or crosshatched velcro strips would solve this problem.

For the ice packets vest to be of practical use in the field, the ice packets would have to be frozen on the vest. This would require at least two vests per crewman since time spent in replacing individual ice packets would result in the ice packets warming up and losing cooling potential, plus the loss of a crewman's time. However, one ice packets vest should be adequate for most aircrew missions and a single ice packets vest per man should suffice for the time required to replace a track or to resupply ammunition.

## 5. CONCLUSIONS

This type of ice packets vest with the maximum number of ice packets (91 ice packets) is capable of providing a total of about 455 watt-hours of cooling over a four-hour period in each of the three hot chamber environments. When



approximately 50% of the torso surface area is covered by ice packets, each additional packet added to the vest increases the torso cooling by a greater degree than when an ice packet is added to a vest with packets covering less than 50% of the torso. For the environmental chamber conditions used in this study, the torso cooling watts for complete torso surface area coverage by ice packets (vest #2 with 91 ice packets attached) over a four-hour heat exposure is independent (within  $\pm 2\%$ ) of the temperature of the hot environment; with less than full coverage the cooling is dependent upon the temperature of the hot environment.

For a given quantity of ice, a complete form-fitting layer of ice over the torso appears to be the most efficient configuration; i.e. it maximizes the heat exchange between the torso and the quantity of ice available and minimizes the heat exchange between the hot environment and the ice.

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## 7. APPENDIX

### A. TEMPERATURE CHANGES WITHIN AN ICE PACKET DURING EXPOSURE TO A HOT CHAMBER ENVIRONMENT

The temperature change with time within an ice packet when the manikin is exposed to a chamber environment of 52°C, 25% relative humidity, is given in Figure 10. The constant ice packet temperature over the first hour is consistent with the approximately constant cooling provided over the torso area, and the decrease when the ice completely melts. A temperature versus time curve for a well-stirred, ice-water mixture would remain constant at the freezing point until all the ice melts, then continually increase in temperature toward the temperature of the surroundings. A temperature curve for a particular ice packet would depend on its location within the vest and its contact pressure with the torso surface, plus the warming effect of the chamber environment. These particular temperatures were measured within the third ice packet up from the waist, located in the front row, adjacent to the zipper closure.

### B. CHANGES IN INTERFACE TEMPERATURES BETWEEN THE TORSO SURFACE AND TWO ICE PACKETS

Interface temperatures between the surface of the torso and two ice packets are given as a function of time in Figure 11. Thermocouples were taped on the outside surface of these packets facing the surface of the upper back area of the torso. This location was selected to minimize disturbing these temperature measurements when the vest was unzipped prior to wetting the manikin "skin". Zero minutes was the time when the vest was dressed on the

manikin. Interface temperatures over the surface of the manikin depend upon the location of the ice packet at which the measurement was made. Ice packets at various locations on the vest would not necessarily have identical interface temperatures at a given time, but would be expected to have similar curve patterns. These two interface temperature curves rise rapidly in temperature over about the first half hour after the vest is dressed on the manikin, then taper off for about an hour, and then continue rising rapidly over the next hour. In any auxiliary cooling system, the greater the cooling provided to the surface of the skin in comparison with the cooling capability lost to the environment, the more efficient the auxiliary cooling system. Possibly, a similar ice vest utilizing the same quantity of ice would provide more effective cooling over the torso if thicker ice packets were used over those areas of the skin where contact between the ice packets and the skin surface is greatest, and thinner ice packets over those areas where contact is least.

TABLE I

COMPONENTS OF THE COMBAT VEHICLE CREWMAN (CVC) ENSEMBLE AND  
THE COMPLETE CHEMICAL PROTECTIVE (CW) SUIT WORN WITH AN ICE  
PACKETS VEST

Coveralls, Combat Vehicle Crewman

CVC Helmet

Socks, Men's 40% cotton, 60% wool

Black leather boots

Suit, Chemical Protective-Coat and Trousers Overgarments

Gas mask/hood

Rubber gloves

TABLE II  
HEAT TRANSFER PROPERTIES OF THE COMBAT VEHICLE CREWMAN (CVC)  
ENSEMBLE WORN WITH THE COMPLETE CHEMICAL PROTECTIVE (CW) SUIT

MANIKIN SECTIONS	CLO	$i_m$	$i_m/clo$
HEAD	2.4	.10	.04
TORSO	3.4	.34	.10
TORSO*	4.3	.34	.08
ARMS	2.7	.40	.15
HANDS	1.3	.05	.04
LEGS	3.1	.05	.16
FEET	1.6	.18	.11
TORSO-ARMS	3.1	.37	.12
TORSO-ARMS-LEGS	3.1	.43	.14
TOTAL	2.6	.31	.12
TOTAL*	2.9	.35	.12

\*Ice packets vest worn; water in packets

TABLE III

ICE PACKETS VEST #1 (72 ice packets)

TORSO HEAT EXCHANGE (WATTS) FOR HOURLY PERIODS DURING EXPOSURE TO THREE HOT CHAMBER ENVIRONMENTS

TORSO COOLING PERIOD		HOT CHAMBER ENVIRONMENT		
HOUR	29°C, 85% RH*	35°C, 62% RH*	52°C, 25%RH*	52°C, 25% RH*
FIRST	162	165	168	151**
SECOND	143	118	93	36**
THIRD	50	50	17***	
FOURTH	26	29		

\*Relative Humidity

\*\*Potential cooling reduced by removing 40% of ice packets from vest

\*\*\*Half-hour average

TABLE IV  
ICE PACKETS VEST #2 (91 ice packets)  
TORSO HEAT EXCHANGE (WATTS) FOR HOURLY PERIODS DURING  
EXPOSURE TO THREE HOT CHAMBER ENVIRONMENTS

TORSO COOLING PERIOD	HOT CHAMBER ENVIRONMENT		
	29°C, 85% RH*	35°C, 62% RH*	52°C, 25% RH*
FIRST	192	192**	188
SECOND	170	160**	140
THIRD	96	87**	75
FOURTH	64	52**	41

\*Relative Humidity

\*\*85 ice packets dressed on ice packets vest #2 for this hot environment



TABLE V  
ICE PACKETS VEST #1 (72 ice packets)  
TORSO COOLING WATTS FOR HOURLY PERIODS DURING EXPOSURE TO THREE HOT CHAMBER ENVIRONMENTS

TORSO COOLING PERIOD		HOT CHAMBER ENVIRONMENT		
HOURLY	29°C, 85% RH*	35°C, 62% RH*	52°C, 25% RH*	52°C, 25% RH*
FIRST	145	134	172	150**
SECOND	125	119	97	42**
THIRD	33	31	20***	
FOURTH	10	15		

\*Relative Humidity

\*\*Potential cooling reduced by removing 40% of ice packets from vest

\*\*\*Half-hour average

TABLE VI

ICE PACKETS VEST #2 (91 ice packets)  
 TORSO COOLING WATTS FOR HOURLY PERIODS DURING EXPOSURE  
 TO THREE HOT CHAMBER ENVIRONMENTS

TORSO COOLING PERIOD	HOT CHAMBER ENVIRONMENT		
	29°C, 85% RH*	35°C, 62% RH*	52°C, 25% RH*
FIRST	175	181**	192
SECOND	153	149**	144
THIRD	79	76**	79
FOURTH	47	41**	45

\*Relative Humidity

\*\*85 ice packets dressed on ice packets vest #2 for this hot environment



Figure 1. Armored fighting vehicle and crewmen of an earlier era when the probability of exposure to chemical and/or biological combat environments was very low.



Figure 2. Photographs of the two ice packets vests used in the study: A. Ice packets vest #1 opened up to show the location of the ice packets attached to the inside of the vest, B. Ice packets vest #2 shown zippered up.



Figure 3. Photograph of the combat vehicle crewman (CVC) ensemble with the complete chemical protective (CW) suit.

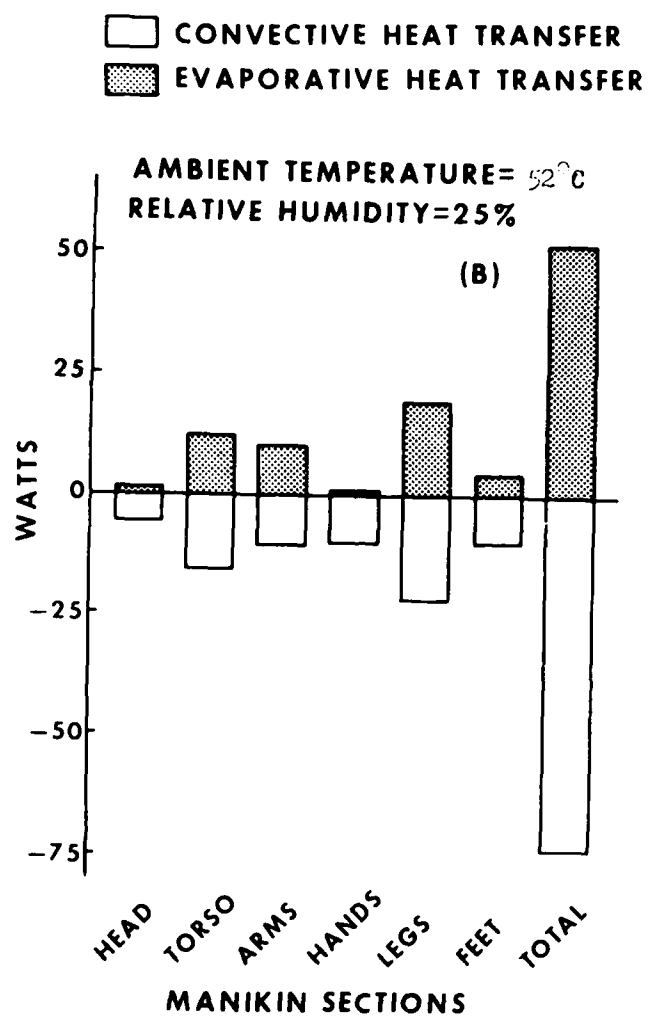


Figure 4. Graphic presentation of the convective and evaporative heat transfer properties of a combat vehicle crewman (CVC) ensemble with closed chemical protective (CW) suit when exposed to a hot environment of 52° (125°F), 25% relative humidity.

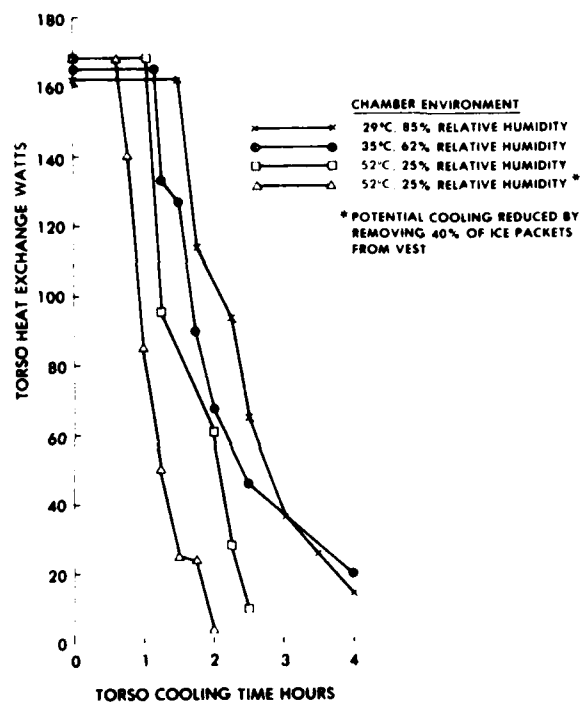


Figure 5. Torso heat exchange (watts) versus torso cooling time (hours) for ice packets vest #1.

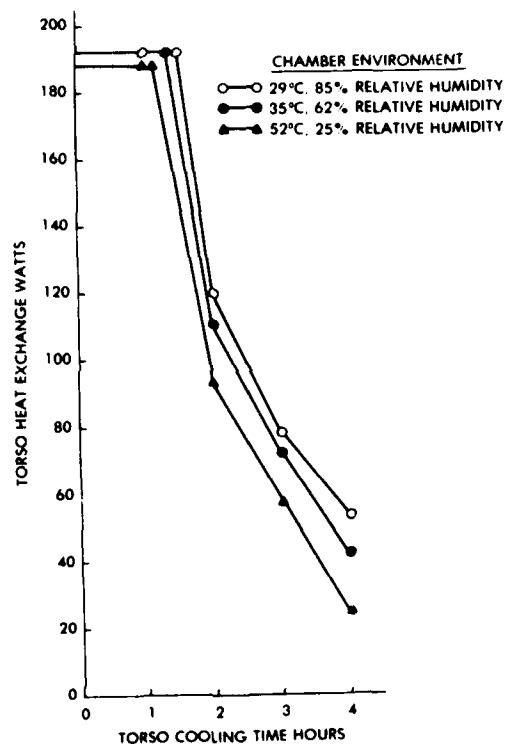


Figure 6. Torso heat exchange (watts) versus torso cooling time (hours) for ice packets vest #2.



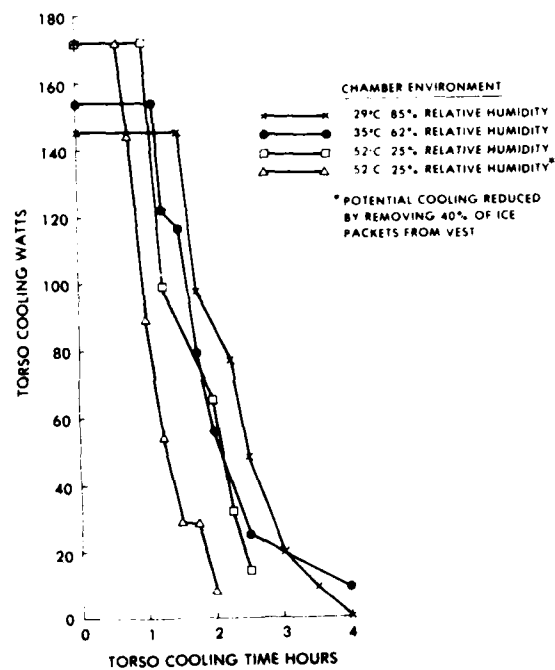


Figure 7. Torso cooling watts versus torso cooling time (hours) for ice packets vest #1.

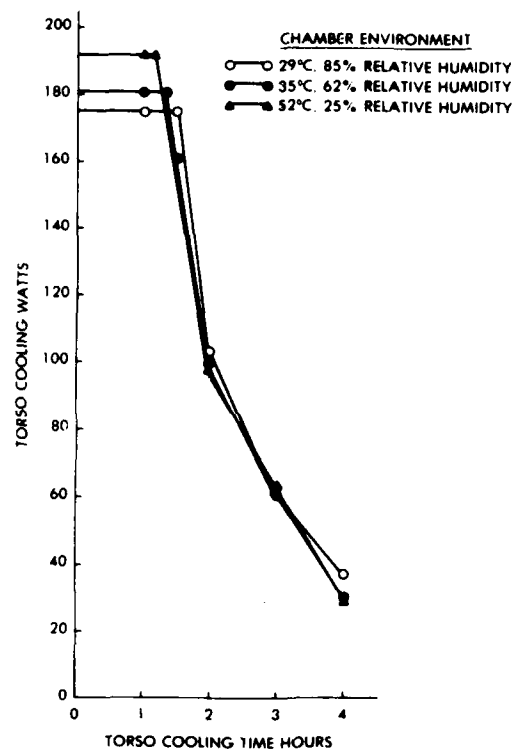


Figure 8. Torso cooling watts versus torso cooling time (hours) for ice packets vest #2.

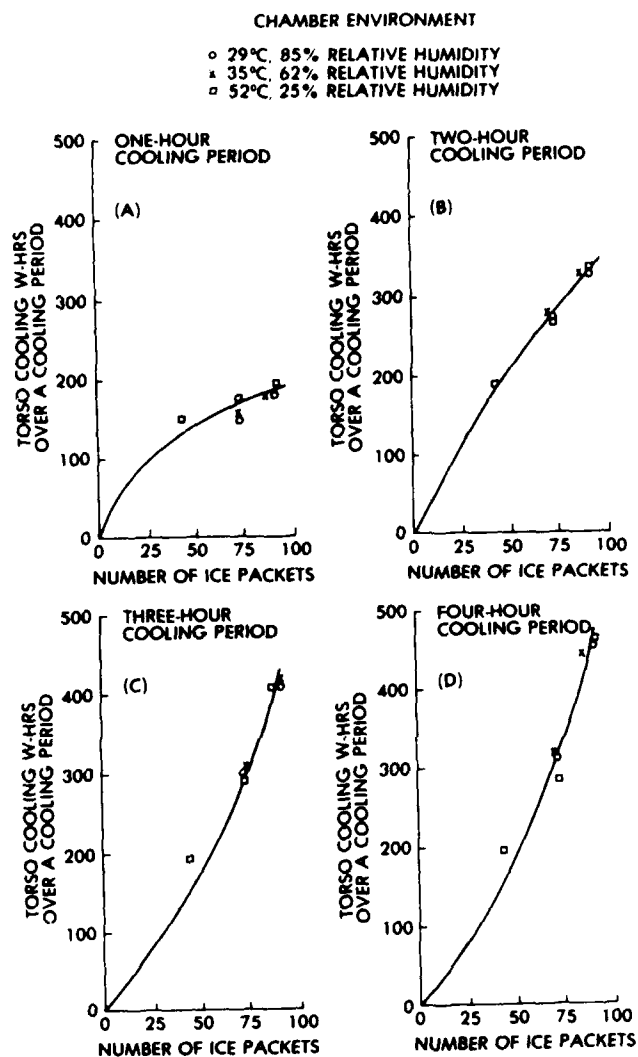


Figure 9. Torso cooling in watt-hours (W-hrs) for a completely wet (i.e. maximal sweating) torso surface versus the number of ice packets attached to a vest: A. One-hour cooling period, B. Two-hour cooling period, C. Three-hour cooling period and D. Four-hour cooling period.

# TEMPERATURE CHANGES WITHIN AN ICE PACKET VS TIME

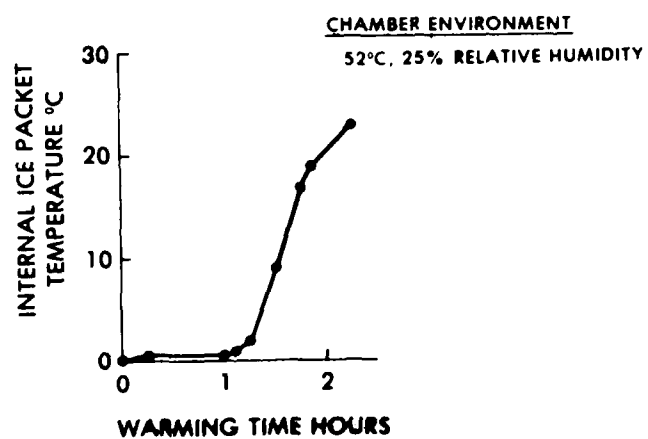


Figure 10. Typical temperature pattern within an ice packet during a torso cooling period when vest #1 is worn.

INTERFACE TEMPERATURE BETWEEN MANIKIN  
SURFACE AND ICE PACKET VERSUS TIME

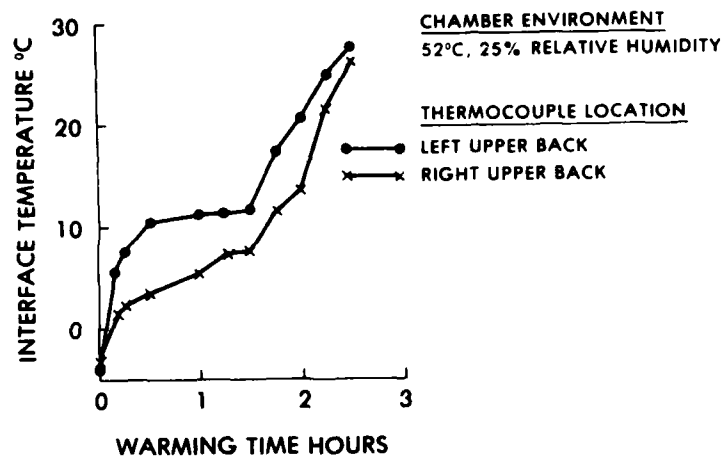


Figure 11. Interface temperature between the torso surface and two ice packet locations in vest #1.

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